AD NO. ___________________________
DTC PROJECT NO. 8-CO-160-UXO-021
REPORT NO. ATC-9814

STANDARDIZED

UXO TECHNOLOGY DEMONSTRATION SITE

BLIND GRID SCORING RECORD NO. 915

SITE LOCATION:
U.S. ARMY YUMA PROVING GROUND

DEMONSTRATOR:
GEOMETRICS, INC.
2190 FORTUNE DRIVE
SAN JOSE, CA 95131

TECHNOLOGY TYPE/PLATFORM:
METALMAPPER (MM)/TOWED

PREPARED BY:
U.S. ARMY ABERDEEN TEST CENTER
ABERDEEN PROVING GROUND, MD 21005-5059

SEPTEMBER 2008

Prepared for:
U.S. ARMY ENVIRONMENTAL COMMAND
ABERDEEN PROVING GROUND, MD 21010-5401

U.S. ARMY DEVELOPMENTAL TEST COMMAND
ABERDEEN PROVING GROUND, MD 21005-5055

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J. Stephen McClung	J.S. McClung Jr.	September 2008
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14. ABSTRACT

This scoring record documents the efforts of Geometrics, Inc. to detect and discriminate inert unexploded ordnance (UXO) utilizing the YPG Standardized UXO Technology Demonstration Site blind grid. This scoring record was coordinated by J. Stephen McClung and the Standardized UXO Technology Demonstration Site Scoring Committee. Organizations on the committee include the U.S. Army Corps of Engineers, the Environmental Security Technology Certification Program, the Strategic Environmental Research and Development Program, the Institute for Defense Analysis, the U.S. Army Environmental Command, and the U.S. Army Aberdeen Test Center.

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SECTION 1. GENERAL INFORMATION

1.1 BACKGROUND

Technologies under development for the detection and discrimination of unexploded ordnance (UXO) require testing so that their performance can be characterized. To that end, Standardized Test Sites have been developed at Aberdeen Proving Ground (APG), Maryland, and U.S. Army Yuma Proving Ground (YPG), Arizona. These test sites provide a diversity of geology, climate, terrain, and weather as well as diversity in ordnance and clutter. Testing at these sites is independently administered and analyzed by the Government for the purposes of characterizing technologies, tracking performance with system development, comparing performance of different systems, and comparing performance in different environments.

The Standardized UXO Technology Demonstration Site Program is a multiagency program spearheaded by the U.S. Army Environmental Command (USAEC). The U.S. Army Aberdeen Test Center (ATC) and the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) provide programmatic support. The program is being funded and supported by the Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP), and the Army Environmental Quality Technology Program (EQT).

1.2 SCORING OBJECTIVES

The objective in the Standardized UXO Technology Demonstration Site Program is to evaluate the detection and discrimination capabilities of a given technology under various field and soil conditions. Inert munitions and clutter items are positioned in various orientations and depths in the ground.

The evaluation objectives are as follows:

a. To determine detection and discrimination effectiveness under realistic scenarios that vary targets, geology, clutter, topography, and vegetation.

b. To determine cost, time, and manpower requirements to operate the technology.

c. To determine the demonstrator's ability to analyze survey data in a timely manner and provide prioritized "Target Lists" with associated confidence levels.

d. To provide independent site management to enable the collection of high quality, ground-truth, geo-referenced data for post-demonstration analysis.

1.2.1 Scoring Methodology

a. The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver-operating

characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}), and those that do not correspond to any known item, termed background alarms.

b. The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the blind grid RESPONSE STAGE, the demonstrator provides the scoring committee with a target response from each and every grid square along with a noise level below which target responses are deemed insufficient to warrant further investigation. This list is generated with minimal processing and, since a value is provided for every grid square, will include signals both above and below the system noise level.

c. The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such and to reject clutter. For the blind grid DISCRIMINATION STAGE, the demonstrator provides the scoring committee with the output of the algorithms applied in the discrimination-stage processing for each grid square. The values in this list are prioritized based on the demonstrator's determination that a grid square is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For digital signal processing, priority ranking is based on algorithm output. For other discrimination approaches, priority ranking is based on human (subjective) judgment. The demonstrator also specifies the threshold in the prioritized ranking that provides optimum performance (i.e., that is expected to retain all detected ordnance and rejects the maximum amount of clutter).

d. The demonstrator is also scored on EFFICIENCY and REJECTION RATIO, which measures the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. EFFICIENCY measures the fraction of detected ordnance retained after discrimination, while the REJECTION RATIO measures the fraction of false alarms rejected. Both measures are defined relative to performance at the demonstrator-supplied level below which all responses are considered noise, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

e. All scoring factors are generated utilizing the Standardized UXO Probability and Plot Program, version 3.1.1.

1.2.2 Scoring Factors

Factors to be measured and evaluated as part of this demonstration include:

a. Response Stage ROC curves:

(1) Probability of Detection (P_d^{res}).

(2) Probability of False Positive (P_{fp}^{res}).

(3) Background Alarm Rate (BAR^{res}) or Probability of Background Alarm (P_{BA}^{res}).

b. Discrimination Stage ROC curves:

(1) Probability of Detection (P_d^{disc}).

(2) Probability of False Positive (P_{fp}^{disc}).

(3) Background Alarm Rate (BAR^{disc}) or Probability of Background Alarm (P_{BA}^{disc}).

c. Metrics:

(1) Efficiency (E).

(2) False Positive Rejection Rate (R_{fp}).

(3) Background Alarm Rejection Rate (R_{BA}).

d. Other:

(1) Probability of Detection by Size and Depth.

(2) Classification by type (i.e., 20-, 40-, 105-mm, etc.).

(3) Location accuracy.

(4) Equipment setup, calibration time, and corresponding man-hour requirements.

(5) Survey time and corresponding man-hour requirements.

(6) Reacquisition/resurvey time and man-hour requirements (if any).

(7) Downtime due to system malfunctions and maintenance requirements.

1.3 STANDARD AND NONSTANDARD INERT ORDNANCE TARGETS

The standard and nonstandard ordnance items emplaced in the test areas are listed in Table 1. Standardized targets are members of a set of specific ordnance items that have identical properties to all other items in the set (caliber, configuration, size, weight, aspect ratio, material, filler, magnetic remanence, and nomenclature). Nonstandard targets are inert ordnance items having properties that differ from those in the set of standardized targets.

TABLE 1. INERT ORDNANCE TARGETS

Standard Type	Nonstandard (NS)
20-mm Projectile M55	20-mm Projectile M55
	20-mm Projectile M97
40-mm Grenades M385	40-mm Grenades M385
40-mm Projectile MKII Bodies	40-mm Projectile M813
BDU-28 Submunition	
BLU-26 Submunition	
M42 Submunition	
57-mm Projectile APC M86	
60-mm Mortar M49A3	60-mm Mortar (JPG)
	60-mm Mortar M49
2.75-inch Rocket M230	2.75-inch Rocket M230
	2.75-inch Rocket XM229
MK 118 ROCKEYE	
81-mm Mortar M374	81-mm Mortar (JPG)
	81-mm Mortar M374
105-mm HEAT Rounds M456	
105-mm Projectile M60	105-mm Projectile M60
155-mm Projectile M483A1	155-mm Projectile M483A
	500-lb Bomb
	M75 Submunition

HEAT = high-explosive antitank.
JPG = Jefferson Proving Ground.

SECTION 2. DEMONSTRATION

2.1 DEMONSTRATOR INFORMATION

2.1.1 Demonstrator Point of Contact (POC) and Address

POC: Mr. D.D. Snyder
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Address: Geometrics, Inc.
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2.1.2 System Description (provided by demonstrator)

With support from the Environmental Security Technology Certification Program (ESTCP), Geometrics is commercializing an advanced electromagnetic induction (EMI) system for UXO detection and characterization. The system will have dual-mode (EM/MAG) capability. Called the MetalMapper (MM), the new system draws elements of its design from advanced systems currently being developed by G&G Sciences, Inc., with funding from NAVSEA (the AOL2 project) and by the Lawrence Berkeley Laboratories (the BUD system) with SERDP and ESTCP funding. The MetalMapper system (fig. 1) is unique and innovative in several respects:

a. Multiple Transmitter Loops. The MM antenna platform includes three mutually orthogonal transmitter loops.

b. 3-Axis Sensor Array. The MM antenna platform includes a spatial array of seven 3-axis receiver antennas (21 independent measurements of the secondary magnetic field).

Electronically Switched TEM Transmitter Loop Driver. The MM system is unique in its ability to drive its transmitter loop array. Under control of the DAQ computer, the output of the transmitter can be directed to any single loop or automatically multiplexed between loops. There is also control of the fundamental waveform period, duty-cycle, and pulse polarity. Typically, however, the loops are driven with a classical bipolar pulse type TEM waveform (i.e., alternating pulse polarity with a 50 percent duty-cycle. Depending on the survey mode (e.g., Static/Dynamic), the fundamental frequency of transmission can be varied from a low of $1.11 \leq f \leq 810$ Hz.

Figure 1. Demonstrator's system, MM/towed.

2.1.3 Data Processing Description (provided by demonstrator)

Acquisition Modes. The MM is, by design, a very flexible system for acquisition of time domain EM (TEM) data. It is beyond the scope of this document to fully describe that flexibility. Simply stated, data are acquired in time blocks that consist of a fixed number of transmitter cycle "Repeats," as illustrated in Figure 3. Both the period (T) and the repeat factor (N) are operator selectable and are varied in multiplicative factors of 3.3. It has two data acquisition modes:

a. Static-Mode Acquisition. In this mode, data-sampled transients from each of the 21 receiver loops plus a channel to sense the transmitter loop current are rectified and stacked for a specified number of acquisition blocks. The resulting transients are (optionally) decimated into a set of logarithmically spaced time gates, after which they are stored to a single binary data file. As its name implies, static-mode acquisition is used to obtain precise data while the antenna platform is parked at a single spatial data point.

b. Continuous-Mode Acquisition. As its name implies, continuous-mode data acquisition results in the data acquisition cycle being repeated until the operator intervenes to halt it. Each of the "DataPoints" is appended to single binary data file; and thus, the resulting data file may consists of 10s or even 100s of data points. This mode is used for dynamic surveying. Typically, a data file consists of all the points acquired along a single profile. Regardless of the acquisition mode, the TEM data thus acquired include the most current GPS position and the platform attitude angles (magnetic heading, pitch, and roll). Depending on the block period (T) and the repeat factor (N), sampling rates of approximately 20 samples/sec can be achieved. The

data are stored as binary formatted files. However, the processing software includes the capability to export the data to a Geosoft Oasis Montaj data base for further QC and map compilation. The processing also includes the capability to export the data to text files and to Matlab™.

Target Selection. The plan is to complete a single dynamic survey over an area that covers both the calibration and blind grids. The survey will consist of parallel profiles acquired with 1-m offsets. Using these data, we will compile a detection parameter map of the surveyed area. The detection map is based on the magnitude of the secondary fields measured at each of the seven tri-axial receiver sensors. The following processing steps, accomplished using Geosoft Oasis Montaj™, are required:

a. MetalMapper data are recorded as binary files. These data are imported directly into an OM data base, where simple editing (e.g., editing line numbers, deselecting duplicate lines, trimming and deleting bad data or stops, etc.) is completed. All other steps are accomplished from within OM using its standard editing and processing capabilities, supplemented where necessary with custom Geosoft Executables (GXs) and Geosoft Scripts (GSs) and Geosoft mathematical expression (EXP) files.

b. Convert Lat/Lon to UTM coordinates.

c. Compute detector gate values for each of the 21 receiver channels.

d. Normalize detector gate values by transmitter current.

e. Select background and remove background (leveling).

f. Generate vector magnitude channels for each of seven tri-axial receiver cubes.

g. Make heading channel for each profile.

h. Split each profile into seven separate profiles, corrected for heading and offset distance from the platform measure point (generates seven parallel profiles with 13-cm offsets).

i. Grid cube amplitude data.

j. Apply grid smoothing filters if necessary.

k. Select targets using an amplitude threshold. The (tunable) parameters are:

(1) Signal amplitude.

(2) Detector gate (step 3).

l. Edit target list based on inspection of profiles.

Target Re-Acquisition and Parameter Estimation. Each of the targets generated from the detection map created from the dynamic data are reacquired with the MetalMapper using a combination of GPS to return to the approximate target location and then a real-time graphics display that allows the operator to center the antenna platform directly over the target. Once the target has been re-acquired, a static data set is acquired at that position. In its static acquisition mode, all three transmitter loops are energized in turn. Typically, a static data set will consist of stack of 50 to 100 data blocks, and the acquisition parameters are selected so that we acquire 8.33-ms or 25-ms transients. These data are recorded in the same standard binary format as are the dynamic data. However, each data file includes only a single (stacked) data point rather than a sequence of data points that are stored in a data file recorded in the ***continuous*** acquisition mode. Each of the static data files is used as input to the MetalMapper Inversion (MMI) program. The MMI program is a physics-based inversion program based on approximating the transient response of compact metallic objects with a point dipole characterized by a time-varying six anisotropic polarizability tensor. MMI is actually a "wrapper" for an implementation of the inverse dipole modeling problem developed by Torquil Smith at LBL in connection with the BUD development project (Smith, 2004). The program provides optimum estimates the following parameters:

a. Target Position (x, y, z). The three-dimensional position of the target with respect to the position of the antenna platform. The MetalMapper includes an apparatus that senses the platform attitude angles (heading, pitch, and roll). Thus, the target position relative to the platform coordinate system can be converted to geographic coordinates.

b. Target Attitude (heading, pitch, roll). The MMI software estimates the target attitude by finding the principal coordinate system for the target polarizability.

c. Principal Polarizability Transients (P1, P2, P3). The MMI software estimates the three principal polarizability transients for the target.

The nine parameters enumerated previously, together, with the inversion fit statistics are the fundamental data derived from the MMI inversion, in particular, the principal polarizability transients. Both targets elongate and exhibit a single axis of symmetry, as indicated by the fact that there is a single "major" polarizability transient and two nearly identical "minor" polarizability curves. A measure of target size is provided by the integration beneath the polarizability curves. Note that the units of the polarizability (rate) transients are m^3/s, or equivalently, $cm^3/\mu s$. Integrating over time to find the area beneath the curve, we end up with units of volume (m^3 or cm^3), as shown in the formula below:

$$P_0 = P(t=0) = \int_0^\infty \frac{dP(t)}{dt} dt$$

Using the RMS value of the three P_0s that can be calculated from the three principal polarizability transients that characterize each of the targets as an indication of size. The parameter P_0 defined in the equation above is an example of a so-called metaparameter that can

be derived from the more fundamental target data that are the three principal polarizability curves. For simple classification by shape, one can define other meta-parameters involving the relationship of the three integrated polarizability parameters (P_0, P_{0y}, and P_{0z}) derived from the equation above to identify elongate targets with an axis of symmetry. Such target features have been used effectively by many to develop classification metrics (Bell, 2000; Grimm, 2003). Among the more useful parameters are the following:

- Transverse Polarizability: $P_{0T} = (P_{0y} + P_{0z})/2$
- Polarizability Ratio: $R_{P0} = P_{0x}/P_{0T}$
- Eccentricity: $E_{P0} = |P_{0y} - P_{0z}|/P_{0x}$

Generally, UXO have a polarizability ratio $R_{P0} \geq 1$ and an eccentricity $E_{P0} << 1$, indicating an elongate body with an axis of symmetry. The thresholds of discrimination for a classifier are determined using a set of training parameters derived from a data set for which the ground truth is known (e.g., the calibration lanes).

Using the training data, developed a classifier based on principles of pattern recognition using the two or three most significant parameters. Typically, the classifier is based on the searching of the nine nearest neighbors in order to find the (binary) decision boundary providing the best division between ordnance (O) and clutter (C). To facilitate the development of a classifier for a particular data set, we use the Duke Pattern Recognition Toolbox (DPRT), a library of MatLab functions for pattern recognition developed by Leslie Collins and her colleagues at Duke University. DPRT supports the development of a variety of classifiers including kNN ('k' nearest neighbors) and FLD (Fischer Linear Discriminant). In our limited experience, the kNN classifier (with k = 3) does better than the FLD classifier and the two. The two parameters are, the eccentricity (E) and the polarizability ratio (R). Overplotted on the scatter plot in color is the surface of the kNN classifier. It should be noted that the axes of the scatter plot represent the Log10 of the associated parameter. The clutter objects with very low eccentricity (E = $P0d_E$) and high polarizability ratio (R = $P0d_R$) are points arising from the shorted loop targets. The clutter objects clustered near the plot origin represent shotputs. It has been plotted together with results from a Fischer Linear Discriminant classifier trained with the same data set. The results from the kNN classifier are effective at discriminating between loops and other targets with good symmetry. However, there is no basis from this data set to discriminate the shotputs from other targets. The AOL2 polarizability results show that a number of target types such as the M75, MK118 Rockeye, and BLU-26 exhibit three nearly identical principal polarizability curves, thus indicating near isotropic polarizability. The shape of the principal polarizabilities for each of the targets are distinctly different.

Training. The performance of the classifier is very much dependent both on the quality of the training data set and on the choice of the relevant parameters used in training. As of yet, we have no feedback on the performance of the classifier as applied to a similar data set acquired over the blind test grid, but belief is that the training data are flawed in the sense that none of the targets in the calibration lanes is truly clutter. In the effort to develop a better classifier, Geometrics intended to work with Anna Sidarovsky, who recently completed a master's degree at the University of Arizona, working with a neural net classifier using a parameter set similar to those we can develop with our data (Szidarovszky, 2008). The prime objective of the work we

plan to conduct at YPG is shake-down and personnel training in preparation for an extended demonstration that will be conducted at ATC later in the year. Mindful of our obligation to submit a target list to ATC for targets identified within the blind grid for scoring, Geometrics will apply either a dKNN or, perhaps, a neural net classifier to the appropriate target parameters for those targets.

2.1.4 Data Submission Format

Data were submitted for scoring in accordance with data submission protocols outlined in the Standardized UXO Technology Demonstration Site Handbook. These submitted data are not included in this report in order to protect ground truth information.

2.1.5 Demonstrator Quality Assurance (QA) and Quality Control (QC) (provided by demonstrator)

a. The MetalMapper data acquisition system integrates data acquired from three (optionally, four) sensors into a sample data point. These systems are position, attitude, EM, and magnetometer. The data from each of the systems are integrated into a single data structure (i.e., a TEMDataPoint). Geometric will perform system checks by returning to a calibration point to acquire data. Typically, the system check consists of a short profile (say 10-m) that is surveyed repeatedly two or more times a day. The profile will be set up in an area of typical background response (i.e., no targets). The calibration survey will consist of a dynamic survey run over a calibration target (typically a shotput) centered along the profile. Geometrics will start the calibration survey by acquiring a static point at the beginning of the calibration line. Then survey dynamically over the target in one direction and then repeat the survey in the opposite direction. Finally, halting the antenna array directly over the target and acquire a static data point.

b. The calibration survey lines, repeated in opposite directions, provide a check of survey timing latency between the acquisition of the GPS position and the acquisition of the EM data. Because of the way we integrate the GPS position directly with the data, no experienced position latencies typical of systems where survey positions and data are merged from independent data files based on a time stamp. However, this experiment provides proof-positive that there is no significant timing latency in the acquisition system. The amplitude of the dynamic survey peaks as they cross over the calibration target also provides a crude measure of the EM drift. A better measure of the drift is provided by the static measurements of the background and the target response. As part of the static background measurement, an established, precise method for putting the cart into a known and repeatable attitude so that a check of the reliability of our orientation system can be completed.

It is notable that our data acquisition system constantly monitors the quality of our GPS positions and provides a visual warning to the operator when the GPS quality for any reason degrades below that of RTK. Furthermore, the acquisition software includes the ability to graphically display data from any point in any data file. This plotting capability allows a data check at any time while in the field.

QA Demonstration Objectives.

a. Two objectives for our work at YPG, to conduct a readiness test of the system prior to a more complete demonstration at APG later in the year; and to provide realistic training to new team members from Zapata/Blackhawk who are joining with us in an ESTCP-funded expanded MetalMapper project that includes participation by UXO contractor personnel. The plan is to use the area that includes the calibration and blind grids to simulate a single, small open field area for system shake-down, development of field procedures, and for personnel training.

b. Station locations will be acquired with an RTK GPS system with the base station located at one of the benchmark locations at the UXO site. The acquisition software constantly monitors the quality of the GPS solution, and when that quality degrades so that the positions are not RTK-quality, a visual warning appears on the DAQ monitor. RTK quality 11 positions with accuracies on the order of centimeters are essential for the high resolution dynamic surveys we intend to conduct. Since Geometrics will not be relying on the lane markers for either the calibration lanes or the blind grid (indeed, for our purposes they serve as a distraction), RTK quality positioning must be maintained during both the dynamic survey and during target re-acquisition for static measurements.

Dynamic Survey. The dynamic survey will be conducted across an area that includes both the calibration lanes and the blind test grid. This survey will be laid out in a manner that ignores the fact that known a priori the direction of the columns in both areas. The survey will be conducted using excitation with a single transmitter loop at 1-m lane intervals. The maps we compile from these data will be used for target detection.

Calibration Checks. Proper functioning of both navigation and EM data acquisition will be assured by conducting periodic calibration surveys as described earlier. These surveys provide a check of the three critical AOL2 subsystems, navigation, attitude, and EM data acquisition as well as serving as a means to sample long-term drift of the instrument response.

Static Surveys. Using the target list generated from the dynamic survey above, Geometrics will re-acquire each target and take a static data set that consists of the EMI response from all three transmitter polarizations. For static measurements, data acquisition parameters will be changed to allow the acquisition of a longer time transient (e.g., T = 0.3 s, N = 9 to provide a 8.3 ms transient decay). It takes approximately 1 minute per target to acquire these data. Experience from previous surveys indicate that there is an ability to re-acquire about 60 to 100 targets/day in this mode of survey.

Calibration Checks. All static surveys will include periodic measurements at a background site and over a calibration target. The frequency of such checks will depend on the drift rates we observe during surveys over the calibration lanes. However, at a minimum, these calibration checks will be run three times daily at the start of the field day, at midday, and at quitting time.

2.1.6 Additional Records

The following record(s) by this vendor can be accessed via the Internet as Microsoft Word documents at www.uxotestsites.org.

2.2 YPG SITE INFORMATION

2.2.1 Location

YPG is located adjacent to the Colorado River in the Sonoran Desert. The UXO Standardized Test Site is located south of Pole Line Road and east of the Countermine Testing and Training Range. The open field range, calibration grid, blind grid, mogul area, and desert extreme area comprise the 350- by 500-meter general test site area. The open field site is the largest of the test sites and measures approximately 200 by 350 meters. To the east of the open field range are the calibration and blind test grids that measure 30 by 40 meters and 40 by 40 meters, respectively. South of the open field is the 135- by 80-meter mogul area consisting of a sequence of man-made depressions. The desert extreme area is located southeast of the open field site and has dimensions of 50 by 100 meters. The desert extreme area, covered with desert-type vegetation, is used to test the performance of different sensor platforms in a more severe desert conditions/environment.

2.2.2 Soil Type

Soil samples were collected at the YPG UXO Standardized Test Site by ERDC to characterize the shallow subsurface (< 3 m). Both surface grab samples and continuous soil borings were acquired. The soils were subjected to several laboratory analyses, including sieve/hydrometer, water content, magnetic susceptibility, dielectric permittivity, X-ray diffraction, and visual description.

Two soil complexes are present within the site: Riverbend-Carrizo and Cristobal-Gunsight. The Riverbend-Carrizo complex is composed of mixed stream alluvium, whereas the Cristobal-Gunsight complex is derived from fan alluvium. The Cristobal-Gunsight complex covers the majority of the site. Most of the soil samples were classified as either a sandy loam or loamy sand, with most samples containing gravel-size particles. All samples had a measured water content less than 7 percent, except for two that contained 11-percent moisture. The majority of soil samples had water content between 1 and 2 percent. Samples containing more than 3 percent were generally deeper than 1 meter.

An X-ray diffraction analysis on four soil samples indicated a basic mineralogy of quartz, calcite, mica, feldspar, magnetite, and some clay. The presence of magnetite imparted a moderate magnetic susceptibility, with volume susceptibilities generally greater than 100 by 105 SI.

For more details concerning the soil properties at the YPG test site, go to www.uxotestsites.org on the Web to view the entire soils description report.

2.2.3 Test Areas

A description of the test site areas at YPG is included in Table 2.

TABLE 2. TEST SITE AREAS

Area	Description
Calibration grid	Contains the 15 standard ordnance items buried in six positions at various angles and depths to allow demonstrator equipment calibration.
Blind grid	Contains 400 grid cells in a 0.16-hectare (0.39-acre) site. The center of each grid cell contains ordnance, clutter, or nothing.

SECTION 3. FIELD DATA

3.1 DATE OF FIELD ACTIVITIES (9 through 13 June 2008)

3.2 AREAS TESTED/NUMBER OF HOURS

Areas tested and total number of hours operated at each site are summarized in Table 3.

TABLE 3. AREAS TESTED AND NUMBER OF HOURS

Area	Number of Hours
Calibration lanes	22.68
Blind grid	17.95

3.3 TEST CONDITIONS

3.3.1 Weather Conditions

A YPG weather station located approximately 1 mile west of the test site was used to record average temperature and precipitation on a half-hour basis for each day of operation. The temperatures listed in Table 4 represent the average temperature during field operations from 0700 to 1700 hours, while precipitation data represent a daily total amount of rainfall. Hourly weather logs used to generate this summary are provided in Appendix B.

TABLE 4. TEMPERATURE/PRECIPITATION DATA SUMMARY

Date, 2008	Average Temperature, ^{o}F	Total Daily Precipitation, in.
9 June	95.6	0.00
10 June	97.5	0.00
11 June	92.8	0.00
12 June	91.8	0.00
13 June	94.2	0.00

3.3.2 Field Conditions

Geometrics surveyed the blind grid on 11 through 13 June 2008. The weather was warm, and the field was dry during the survey.

3.3.3 Soil Moisture

Three soil probes were placed at various locations within the site to capture soil moisture data: calibration, mogul, open field, and desert extreme areas. Measurements were collected in percent moisture and were taken twice daily (morning and afternoon) from five different soil depths (1 to 6 in., 6 to 12 in., 12 to 24 in., 24 to 36 in., and 36 to 48 in.) from each probe. Soil moisture logs are included in Appendix C.

3.4 FIELD ACTIVITIES

3.4.1 Setup/Mobilization

These activities included initial mobilization and daily equipment preparation and breakdown. A three-person crew took 1 hour and 10 minutes to perform the initial setup and mobilization. There was 22 minutes of daily equipment preparation and 13 minutes end of the day equipment breakdown.

3.4.2 Calibration

Geometrics spent a total of 22 hours and 41 minutes in the calibration lanes, of which 17 hours and 38 minutes were spent collecting data.

3.4.3 Downtime Occasions

Occasions of downtime are grouped into five categories: equipment/data checks or equipment maintenance, equipment failure and repair, weather, demonstration site issues, or breaks/lunch. All downtime is included for the purposes of calculating labor costs (section 5) except for downtime due to demonstration site issues. Demonstration site issues, while noted in the daily log, are considered nonchargeable downtime for the purposes of calculating labor costs and are not discussed. Breaks and lunches are discussed in this section and billed to the total site survey area.

3.4.3.1 Equipment/data checks, maintenance. Equipment data checks and maintenance activities accounted for 2 hours and 26 minutes of site usage time. These activities included changing out batteries and performing routine data checks to ensure the data were being properly recorded/collected. Geometrics spent an additional 1 hour and 7 minutes for breaks and lunches.

3.4.3.2 Equipment failure or repair. No time was needed to resolve equipment failures that occurred while surveying the blind grid.

3.4.3.3 Weather. No weather delays occurred during the survey.

3.4.4 Data Collection

Geometrics spent a total time of 17 hours and 57 minutes in the blind grid area, of which 13 hours and 49 minutes was spent collecting data.

3.4.5 Demobilization

The Geometrics survey crew went on to conduct a full demonstration of the site. Therefore, demobilization did not occur until 13 June 2008. On that day, it took the crew 1 hour and 10 minutes to break down and pack up their equipment.

3.5 PROCESSING TIME

Geometrics submitted the raw data from the demonstration activities on the last day of the demonstration, as required. The scoring submittal data were provided within the required 30-day time frame.

3.6 DEMONSTRATOR'S FIELD PERSONNEL

Geophysicist: Donald Snyder
Geophysicist: David George
Geophysicist: Steffan Hodges

3.7 DEMONSTRATOR'S FIELD SURVEYING METHOD

Geometrics surveyed the blind grid in a linear fashion in a north-to-south and west-to-east direction.

3.8 SUMMARY OF DAILY LOGS

Daily logs captured all field activities during this demonstration and are located in Appendix D. Activities pertinent to this specific demonstration are indicated in highlighted text.

SECTION 4. TECHNICAL PERFORMANCE RESULTS

4.1 ROC CURVES USING ALL ORDNANCE CATEGORIES

The probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive are shown in Figure 2. Both probabilities plotted against their respective background alarm rate are shown in Figure 3. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

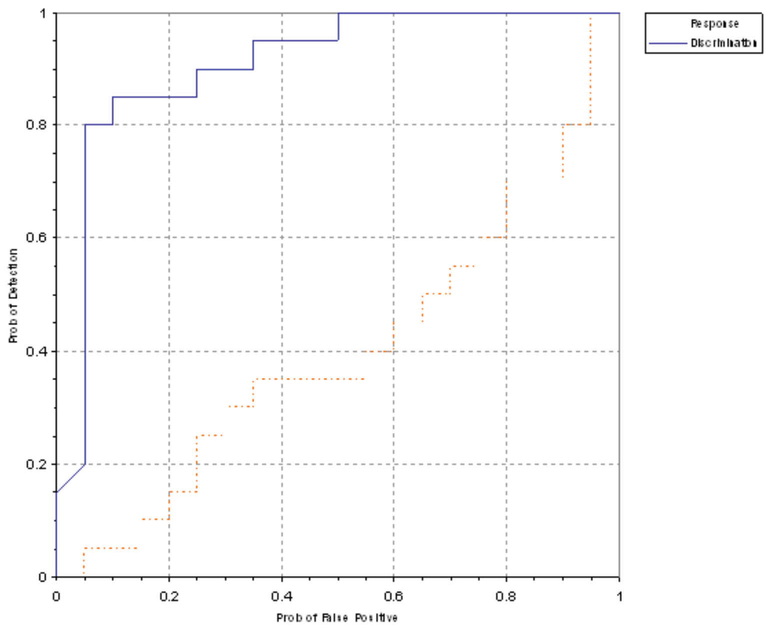

Figure 2. MM/towed blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

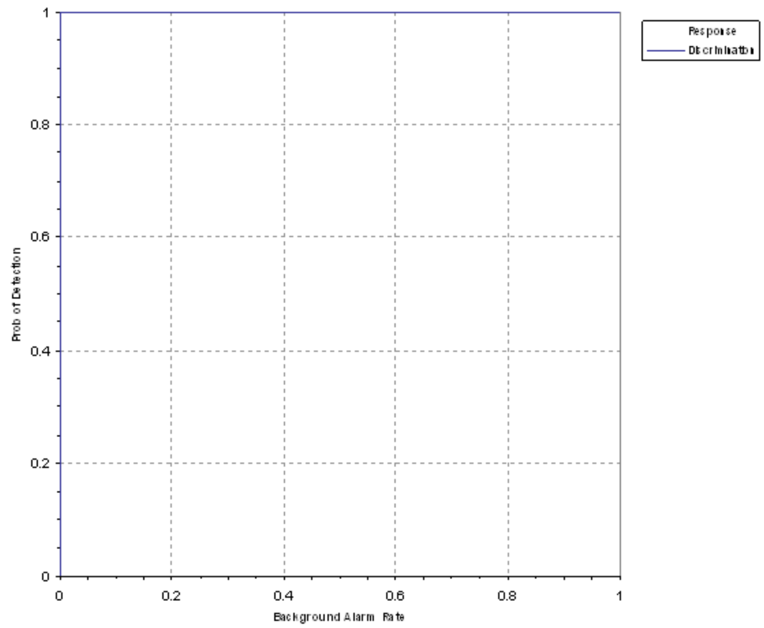

Figure 3. MM/towed blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

4.2 ROC CURVES USING ORDNANCE LARGER THAN 20 MM

The probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive when only targets larger than 20 mm are scored are shown in Figure 4. Both probabilities plotted against their respective background alarm rate are shown in Figure 5. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

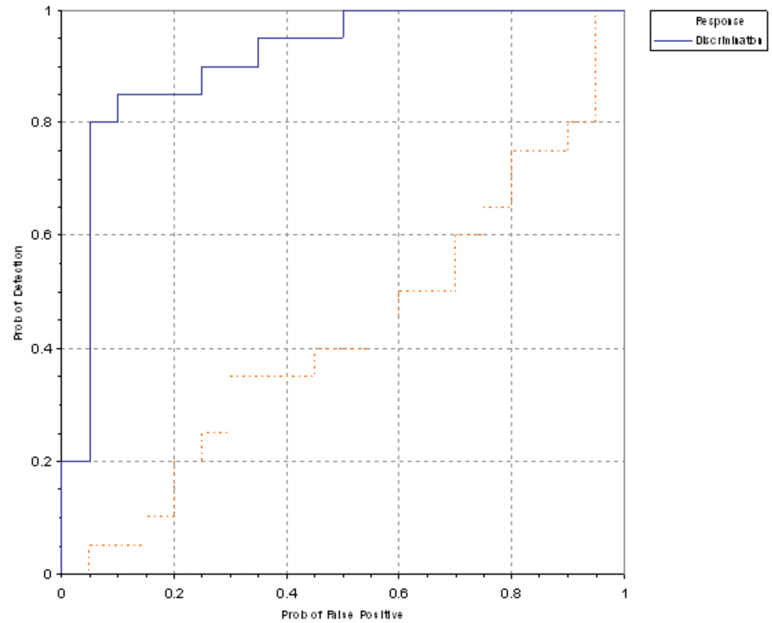

Figure 4. MM/towed blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

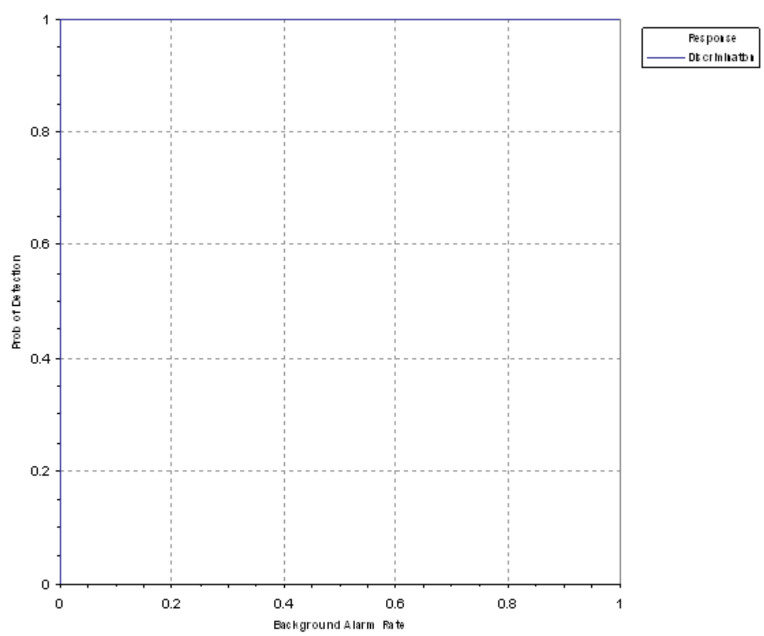

Figure 5. MM/towed blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

4.3 PERFORMANCE SUMMARIES

Results for the open field test broken out by size, depth, and nonstandard ordnance are presented in Table 5 (for cost results, see section 5). Results by size and depth include both standard and nonstandard ordnance. The results by size show how well the demonstrator did at detecting/discriminating ordnance of a certain caliber range (see app A for size definitions). The results are relative to the number of ordnance items emplaced. Depth is measured from the geometric center of anomalies.

The RESPONSE STAGE results are derived from the list of anomalies above the demonstrator-provided noise level. The results for the DISCRIMINATION STAGE are derived from the demonstrator's recommended threshold for optimizing UXO field cleanup by minimizing false digs and maximizing ordnance recovery. The lower 90-percent confidence limit on probability of detection and probability of false positive was calculated assuming that the number of detections and false positives are binomially distributed random variables. All results in Table 5 have been rounded to protect the ground truth. However, lower confidence limits were calculated using actual results.

TABLE 5. SUMMARY OF BLIND GRID RESULTS FOR THE MM/TOWED

Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	1.00	1.00	0.95	1.00	1.00	0.95	1.00	1.00	0.85
P_d Low 90% Conf	0.95	0.96	0.87	0.95	0.91	0.75	0.95	0.92	0.55
P_d Upper 90% Conf	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99
P_{fp}	0.95	-	-	-	-	-	0.95	1.00	N/A
P_{fp} Low 90% Conf	0.94	-	-	-	-	-	0.92	0.93	0.00
P_{fp} Upper 90% Conf	0.99	-	-	-	-	-	0.99	1.00	1.00
P_{ba}	0.00	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	1.00	1.00	0.95	1.00	1.00	0.95	1.00	1.00	0.85
P_d Low 90% Conf	0.95	0.96	0.87	0.95	0.91	0.75	0.95	0.92	0.55
P_d Upper 90% Conf	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99
P_{fp}	0.50	-	-	-	-	-	0.45	0.65	N/A
P_{fp} Low 90% Conf	0.44	-	-	-	-	-	0.37	0.50	0.00
P_{fp} Upper 90% Conf	0.56	-	-	-	-	-	0.52	0.75	1.00
P_{ba}	0.00	-	-	-	-	-	-	-	-

Response Stage Noise Level: 0.05.
Recommended Discrimination Stage Threshold: 3.00.

Note: The recommended discrimination stage threshold values are provided by the demonstrator.

4.4 EFFICIENCY, REJECTION RATES, AND TYPE CLASSIFICATION

Efficiency and rejection rates are calculated to quantify the discrimination ability at specific points of interest on the ROC curve: (1) at the point where no decrease in P_d is suffered (i.e., the efficiency is by definition equal to one) and (2) at the operator selected threshold. These values are reported in Table 6.

TABLE 6. EFFICIENCY AND REJECTION RATES

	Efficiency (E)	False Positive Rejection Rate	Background Alarm Rejection Rate
At Operating Point	1.00	0.49	N/A
With No Loss of P_d	1.00	0.49	N/A

At the demonstrator's recommended setting, the ordnance items that were detected and correctly discriminated were further scored on whether their correct type could be identified (table 7). Correct type examples include 20-mm projectile, 105-mm HEAT Projectile, and 2.75-inch Rocket. A list of the standard type declaration required for each ordnance item was provided to demonstrators prior to testing. For example, the standard type for the three example items are 20 mmP, 105 H, and 2.75 in., respectively.

TABLE 7. CORRECT TYPE CLASSIFICATION OF TARGETS CORRECTLY DISCRIMINATED AS UXO

Size	Percentage Correct
Small	0.74
Medium	0.65
Large	0.79
Overall	0.72

4.5 LOCATION ACCURACY

The mean location error and standard deviations appear in Table 8. These calculations are based on average missed depth for ordnance correctly identified in the discrimination stage. Depths are measured from the closest point of the ordnance to the surface. For the blind grid, only depth errors are calculated because (X, Y) positions are known to be the centers of each grid square.

TABLE 8. MEAN LOCATION ERROR AND STANDARD DEVIATION (M)

	Mean	Standard Deviation
Depth	-0.003	0.198

SECTION 5. ON-SITE LABOR COSTS

A standardized estimate for labor costs associated with this effort was calculated as follows: the first person at the test site was designated supervisor, the second person was designated data analyst, and the third and following personnel were considered field support. Standardized hourly labor rates were charged by title: supervisor at $95.00/hour, data analyst at $57.00/hour, and field support at $28.50/hour.

Government representatives monitored on-site activity. All on-site activities were grouped into one of ten categories: initial setup/mobilization, daily setup/stop, calibration, data collection, downtime due to break/lunch, downtime due to equipment failure, downtime due to equipment/data checks or maintenance, downtime due to weather, downtime due to demonstration site issue, or demobilization. See Appendix D for the daily activity log. See section 3.4 for a summary of field activities.

The standardized cost estimate associated with the labor needed to perform the field activities is presented in Table 9. Note that calibration time includes time spent in the calibration lanes as well as field calibrations. Site survey time includes daily setup/stop time, collecting data, breaks/lunch, downtime due to equipment/data checks or maintenance, downtime due to failure, and downtime due to weather.

TABLE 9. ON-SITE LABOR COSTS

	No. People	Hourly Wage	Hours	Cost
Initial setup				
Supervisor	1	$95.00	1.16	$110.20
Data analyst	1	57.00	1.16	66.12
Field support	1	28.50	1.16	33.06
Subtotal				**$209.38**
Calibration				
Supervisor	1	$95.00	22.68	$2154.60
Data analyst	1	57.00	22.68	1292.76
Field support	1	28.50	22.68	646.38
Subtotal				**$4093.74**
Site survey				
Supervisor	1	$95.00	17.95	$1705.25
Data analyst	1	57.00	17.95	1023.15
Field support	1	28.50	17.95	511.58
Subtotal				**$3239.98**

See notes at end of table.

TABLE 9 (CONT'D)

	No. People	Hourly Wage	Hours	Cost
Demobilization				
Supervisor	1	$95.00	1.16	$110.20
Data analyst	1	57.00	1.16	66.12
Field support	1	28.50	1.16	33.06
Subtotal				**$209.38**
Total				**$7752.48**

Notes: Calibration time includes time spent in the calibration lanes as well as calibration before each data run.
Site survey time includes daily setup/stop time, collecting data, breaks/lunch, and downtime due to system maintenance, failure, and weather.

SECTION 6. COMPARISON OF RESULTS TO DATE

No comparisons to date.

SECTION 7. APPENDIXES

APPENDIX A. TERMS AND DEFINITIONS

GENERAL DEFINITIONS

Anomaly: Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

Detection: An anomaly location that is within R_{halo} of an emplaced ordnance item.

Emplaced Ordnance: An ordnance item buried by the government at a specified location in the test site.

Emplaced Clutter: A clutter item (i.e., non-ordnance item) buried by the government at a specified location in the test site.

R_{halo}: A pre-determined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. If multiple declarations lie within R_{halo} of any item (clutter or ordnance), the declaration with the highest signal output within the R_{halo} will be utilized. For the purpose of this program, a circular halo 0.5 meters in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meters in length. When ordnance items are longer than 0.6 meters, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the length of the ordnance plus 1 meter.

Small Ordnance: Caliber of ordnance less than or equal to 40 mm (includes 20-mm projectile, 40-mm projectile, submunitions BLU-26, BLU-63, and M42).

Medium Ordnance: Caliber of ordnance greater than 40 mm and less than or equal to 81 mm (includes 57-mm projectile, 60-mm mortar, 2.75 in. Rocket, MK118 Rockeye, 81-mm mortar).

Large Ordnance: Caliber of ordnance greater than 81 mm (includes 105-mm HEAT, 105-mm projectile, 155-mm projectile, 500-pound bomb).

Shallow: Items buried less than 0.3 meter below ground surface.

Medium: Items buried greater than or equal to 0.3 meter and less than 1 meter below ground surface.

Deep: Items buried greater than or equal to 1 meter below ground surface.

Response Stage Noise Level: The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the blind grid test area.

Discrimination Stage Threshold: The demonstrator selected threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

Binomially Distributed Random Variable: A random variable of the type which has only two possible outcomes, say success and failure, is repeated for n independent trials with the probability p of success and the probability 1-p of failure being the same for each trial. The number of successes x observed in the n trials is an estimate of p and is considered to be a binomially distributed random variable.

RESPONSE AND DISCRIMINATION STAGE DATA

The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver operating characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}) and those that do not correspond to any known item, termed background alarms.

The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the RESPONSE STAGE, the demonstrator provides the scoring committee with the location and signal strength of all anomalies that the demonstrator has deemed sufficient to warrant further investigation and/or processing as potential emplaced ordnance items. This list is generated with minimal processing (e.g., this list will include all signals above the system noise threshold). As such, it represents the most inclusive list of anomalies.

The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such, and to reject clutter. For the same locations as in the RESPONSE STAGE anomaly list, the DISCRIMINATION STAGE list contains the output of the algorithms applied in the discrimination-stage processing. This list is prioritized based on the demonstrator's determination that an anomaly location is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For electronic signal processing, priority ranking is based on algorithm output. For other systems, priority ranking is based on human judgment. The demonstrator also selects the threshold that the demonstrator believes will provide "optimum" system performance, (i.e., that retains all the detected ordnance and rejects the maximum amount of clutter).

Note: The two lists provided by the demonstrator contain identical numbers of potential target locations. They differ only in the priority ranking of the declarations.

RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection (P_d^{res}): P_d^{res} = (No. of response-stage detections)/(No. of emplaced ordnance in the test site).

Response Stage False Positive (fp^{res}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Response Stage Probability of False Positive (P_{fp}^{res}): P_{fp}^{res} = (No. of response-stage false positives)/(No. of emplaced clutter items).

Response Stage Background Alarm (ba^{res}): An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm (P_{ba}^{res}): Blind Grid only: P_{ba}^{res} = (No. of response-stage background alarms)/(No. of empty grid locations).

Response Stage Background Alarm Rate (BAR^{res}): Open Field only: BAR^{res} = (No. of response-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{res}, P_{fp}^{res}, P_{ba}^{res}, and BAR^{res} are functions of t^{res}, the threshold applied to the response-stage signal strength. These quantities can therefore be written as $P_d^{res}(t^{res})$, $P_{fp}^{res}(t^{res})$, $P_{ba}^{res}(t^{res})$, and $BAR^{res}(t^{res})$.

DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to non-ordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection (P_d^{disc}): P_d^{disc} = (No. of discrimination-stage detections)/(No. of emplaced ordnance in the test site).

Discrimination Stage False Positive (fp^{disc}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Discrimination Stage Probability of False Positive (P_{fp}^{disc}): P_{fp}^{disc} = (No. of discrimination stage false positives)/(No. of emplaced clutter items).

Discrimination Stage Background Alarm (ba^{disc}): An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm (P_{ba}^{disc}): P_{ba}^{disc} = (No. of discrimination-stage background alarms)/(No. of empty grid locations).

Discrimination Stage Background Alarm Rate (BAR^{disc}): BAR^{disc} = (No. of discrimination-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{disc}, P_{fp}^{disc}, P_{ba}^{disc}, and BAR^{disc} are functions of t^{disc}, the threshold applied to the discrimination-stage signal strength. These quantities can therefore be written as $P_d^{disc}(t^{disc})$, $P_{fp}^{disc}(t^{disc})$, $P_{ba}^{disc}(t^{disc})$, and $BAR^{disc}(t^{disc})$.

RECEIVER-OPERATING CHARACERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed based on the above definitions. The ROC curves plot the relationship between P_d versus P_{fp} and P_d versus BAR or P_{ba} as the threshold applied to the signal strength is varied from its minimum (t_{min}) to its maximum (t_{max}) value.[1] Figure A-1 shows how P_d versus P_{fp} and P_d versus BAR are combined into ROC curves. Note that the "res" and "disc" superscripts have been suppressed from all the variables for clarity.

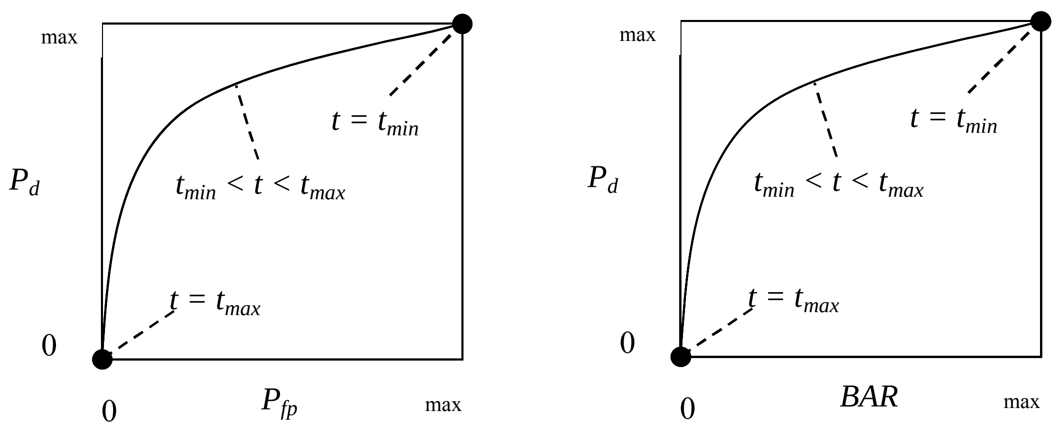

Figure A-1. ROC curves for open field testing. Each curve applies to both the response and discrimination stages.

[1]Strictly speaking, ROC curves plot the P_d versus P_{ba} over a pre-determined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an open field scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the open field ROC curves do not have information from low signal-output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the blind grid test sites are true ROC curves.

METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E): $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$; Measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage tmin) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

False Positive Rejection Rate (R_{fp}): $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$; Measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage tmin). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate (R_{ba}):

Blind grid: $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$.
Open field: $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})]$).

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

CHI-SQUARE COMPARISON EXPLANATION:

The Chi-square test for differences in probabilities (or 2 x 2 contingency table) is used to analyze two samples drawn from two different populations to see if both populations have the same or different proportions of elements in a certain category. More specifically, two random samples are drawn, one from each population, to test the null hypothesis that the probability of event A (some specified event) is the same for both populations (ref 3).

A 2 x 2 contingency table is used in the Standardized UXO Technology Demonstration Site Program to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly degraded by the more challenging terrain feature introduced. The test statistic of the 2 x 2 contingency table is the

Chi-square distribution with one degree of freedom. Since an association between the more challenging terrain feature and relatively degraded performance is sought, a one-sided test is performed. A significance level of 0.05 is chosen which sets a critical decision limit of 2.71 from the Chi-square distribution with one degree of freedom. It is a critical decision limit because if the test statistic calculated from the data exceeds this value, the two proportions tested will be considered significantly different. If the test statistic calculated from the data is less than this value, the two proportions tested will be considered not significantly different.

An exception must be applied when either a 0 or 100 percent success rate occurs in the sample data. The Chi-square test cannot be used in these instances. Instead, Fischer's test is used and the critical decision limit for one-sided tests is the chosen significance level, which in this case is 0.05. With Fischer's test, if the test statistic is less than the critical value, the proportions are considered to be significantly different.

Standardized UXO Technology Demonstration Site examples, where blind grid results are compared to those from the open field and open field results are compared to those from one of the scenarios, follow. It should be noted that a significant result does not prove a cause and effect relationship exists between the two populations of interest; however, it does serve as a tool to indicate that one data set has experienced a degradation in system performance at a large enough level than can be accounted for merely by chance or random variation. Note also that a result that is not significant indicates that there is not enough evidence to declare that anything more than chance or random variation within the same population is at work between the two data sets being compared.

Demonstrator X achieves the following overall results after surveying each of the three progressively more difficult areas using the same system (results indicate the number of ordnance detected divided by the number of ordnance emplaced):

	Blind grid	Open field	Moguls
P_d^{res}	100/100 = 1.0	8/10 = .80	20/33 = .61
P_d^{disc}	80/100 = 0.80	6/10 = .60	8/33 = .24

P_d^{res}: BLIND GRID versus OPEN FIELD. Using the example data above to compare probabilities of detection in the response stage, all 100 ordnance out of 100 emplaced ordnance items were detected in the blind grid while 8 ordnance out of 10 emplaced were detected in the open field. Fischer's test must be used since a 100 percent success rate occurs in the data. Fischer's test uses the four input values to calculate a test statistic of 0.0075 that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.80) is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the detection ability of demonstrator X's system seems to have been degraded in the open field relative to results from the blind grid using the same system.

P_d^{disc}: BLIND GRID versus OPEN FIELD. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 emplaced ordnance items were correctly discriminated as ordnance in blind grid testing while 6 ordnance out of 10 emplaced were correctly discriminated as such in open field-testing. Those four values are used to calculate a test statistic of 1.12. Since the test statistic is less than the critical value of 2.71, the two discrimination stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{res}: OPEN FIELD versus MOGULS. Using the example data above to compare probabilities of detection in the response stage, 8 out of 10 and 20 out of 33 are used to calculate a test statistic of 0.56. Since the test statistic is less than the critical value of 2.71, the two response stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{disc}: OPEN FIELD versus MOGULS. Using the example data above to compare probabilities of detection in the discrimination stage, 6 out of 10 and 8 out of 33 are used to calculate a test statistic of 2.98. Since the test statistic is greater than the critical value of 2.71, the smaller discrimination stage detection rate is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the ability of demonstrator X to correctly discriminate seems to have been degraded by the mogul terrain relative to results from the flat open field using the same system.

APPENDIX B.   DAILY WEATHER LOGS

9 June 2008		
Time	**Temperature, ^oF**	**Precipitation, in.**
0700	76.4	0.0
0800	81.6	0.0
0900	87.1	0.0
1000	91.4	0.0
1100	95.5	0.0
1200	99.4	0.0
1300	101.7	0.0
1400	103.6	0.0
1500	104.5	0.0
1600	105.0	0.0
1700	105.4	0.0
10 June 2008		
0700	76.3	0.0
0800	84.4	0.0
0900	90.4	0.0
1000	94.3	0.0
1100	98.1	0.0
1200	100.6	0.0
1300	103.0	0.0
1400	105.0	0.0
1500	106.3	0.0
1600	106.9	0.0
1700	107.1	0.0
11 June 2008		
0700	78.6	0.0
0800	82.1	0.0
0900	86.0	0.0
1000	89.0	0.0
1100	91.7	0.0
1200	94.5	0.0
1300	97.0	0.0
1400	98.9	0.0
1500	100.5	0.0
1600	101.0	0.0
1700	101.8	0.0

12 June 2008		
Time	**Temperature, °F**	**Precipitation, in.**
0700	74.6	0.0
0800	79.5	0.0
0900	84.5	0.0
1000	88.9	0.0
1100	91.8	0.0
1200	93.6	0.0
1300	96.7	0.0
1400	99.1	0.0
1500	100.0	0.0
1600	100.3	0.0
1700	100.5	0.0
13 June 2008		
0700	77.1	0.0
0800	83.5	0.0
0900	87.0	0.0
1000	90.6	0.0
1100	93.5	0.0
1200	96.1	0.0
1300	98.5	0.0
1400	100.6	0.0
1500	102.2	0.0
1600	103.2	0.0
1700	103.8	0.0

APPENDIX C. SOIL MOISTURE

9 June 2008			
Times: N/A and 1400			
Probe Location	**Layer, in.**	**AM Reading, %**	**PM Reading, %**
Calibration area	0 to 6	N/A	4.8
	6 to 12		5.7
	12 to 24		9.1
	24 to 36		4.3
	36 to 48		9.2
Mogul area	0 to 6		1.7
	6 to 12		6.6
	12 to 24		5.0
	24 to 36		9.9
	36 to 48		15.4
Desert extreme area	0 to 6		11.3
	6 to 12		38.2
	12 to 24		3.6
	24 to 36		7.3
	36 to 48		8.2
10 June 2008			
Times: 0900 and 1300			
Probe Location	**Layer, in.**	**AM Reading, %**	**PM Reading, %**
Calibration area	0 to 6	2.8	3.8
	6 to 12	7.7	7.8
	12 to 24	9.7	9.6
	24 to 36	4.0	4.2
	36 to 48	9.6	9.4
Mogul area	0 to 6	2.0	2.1
	6 to 12	3.7	3.7
	12 to 24	6.3	6.5
	24 to 36	10.8	10.7
	36 to 48	14.6	14.8
Desert extreme area	0 to 6	11.1	11.3
	6 to 12	38.2	38.2
	12 to 24	7.7	3.4
	24 to 36	29.1	7.6
	36 to 48	4.5	4.7

11 June 2008			
Times: 0700 and 1300			
Probe Location	**Layer, in.**	**AM Reading, %**	**PM Reading, %**
Calibration area	0 to 6	4.8	4.7
	6 to 12	5.7	5.9
	12 to 24	9.1	9.1
	24 to 36	4.2	4.3
	36 to 48	9.3	9.2
Mogul area	0 to 6	1.7	2.2
	6 to 12	6.6	6.7
	12 to 24	5.0	5.6
	24 to 36	9.9	9.8
	36 to 48	15.4	15.5
Desert extreme area	0 to 6	11.1	11.2
	6 to 12	38.2	38.2
	12 to 24	3.9	3.6
	24 to 36	7.3	7.5
	36 to 48	8.1	8.3
12 June 2008			
Times: 0500 and 1300			
Probe Location	**Layer, in.**	**AM Reading, %**	**PM Reading, %**
Calibration area	0 to 6	4.0	2.2
	6 to 12	7.4	9.1
	12 to 24	9.1	9.0
	24 to 36	4.3	4.3
	36 to 48	9.4	9.3
Mogul area	0 to 6	2.0	4.0
	6 to 12	3.4	3.4
	12 to 24	5.5	6.1
	24 to 36	10.5	10.5
	36 to 48	14.8	14.6
Desert extreme area	0 to 6	40.0	11.1
	6 to 12	38.2	38.2
	12 to 24	3.6	2.4
	24 to 36	7.2	7.7
	36 to 48	7.2	7.8

13 June 2008			
Times: 0500 and N/A			
Probe Location	**Layer, in.**	**AM Reading, %**	**PM Reading, %**
Calibration area	0 to 6	4.0	N/A
	6 to 12	8.9	
	12 to 24	9.0	
	24 to 36	4.5	
	36 to 48	9.3	
Mogul area	0 to 6	4.0	
	6 to 12	4.3	
	12 to 24	5.3	
	24 to 36	10.3	
	36 to 48	15.1	
Desert extreme area	0 to 6	11.1	
	6 to 12	38.2	
	12 to 24	2.3	
	24 to 36	7.3	
	36 to 48	7.8	

APPENDIX D. DAILY ACTIVITY LOGS

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration, min	Operational Status	Operational Status Comments	Track Method	Pattern	Field Conditions	
06/09/2008	3	CALIBRATION LANES	700	810	70	INITIAL SETUP	Setting up test equipment and initial calibration.	NA	NA	Sunny	Cool
06/09/2008	3	CALIBRATION LANES	810	945	95	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/09/2008	3	CALIBRATION LANES	945	950	5	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Verifying data.	NA	NA	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	950	1230	160	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	1230	1241	11	DOWNTIME DUE TO EQUIPMENT FAILURE	Removing skid from under unit.	NA	NA	Sunny	Warm
06/09/2008	2	CALIBRATION LANES	1241	1340	59	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	1340	1357	17	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Replacing batteries in unit.	NA	NA	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	1357	1452	55	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	1452	1502	10	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Replacing batteries in handheld PC.	NA	NA	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	1502	1510	8	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/09/2008	3	CALIBRATION LANES	1510	1517	7	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
06/10/2008	2	CALIBRATION LANES	445	521	36	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
06/10/2008	2	CALIBRATION LANES	521	705	104	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/10/2008	2	CALIBRATION LANES	705	726	21	BREAK/LUNCH	Break	NA	NA	Sunny	Cool
06/10/2008	2	CALIBRATION LANES	726	833	67	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/10/2008	2	CALIBRATION LANES	833	847	14	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Switching to hand cart.	NA	NA	Sunny	Warm

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration, min	Operational Status	Operational Status Comments	Track Method	Pattern	Field Conditions	
06/10/2008	2	CALIBRATION LANES	847	1010	83	COLLECTING DATA	Collecting data, performed static testing.	GPS	Linear	Sunny	Warm
06/10/2008	3	CALIBRATION LANES	1010	1017	7	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Replacing batteries.	NA	NA	Sunny	Warm
06/10/2008	3	CALIBRATION LANES	1017	1250	153	COLLECTING DATA	Collecting data, performed static testing.	GPS	Linear	Sunny	Warm
06/10/2008	3	CALIBRATION LANES	1250	1310	20	BREAK/LUNCH	Break	NA	NA	Sunny	Warm
06/10/2008	3	CALIBRATION LANES	1310	1402	52	COLLECTING DATA	Collecting data, performed static testing.	GPS	Linear	Sunny	Hot
06/10/2008	3	CALIBRATION LANES	1402	1435	33	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Hot
06/11/2008	3	CALIBRATION LANES	457	520	23	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
06/11/2008	3	BLIND TEST GRID	520	655	95	COLLECTING DATA	Collecting data, south to north, west to east.	GPS	Linear	Sunny	Cool
06/11/2008	3	BLIND TEST GRID	655	722	27	BREAK/LUNCH	Break	NA	NA	Sunny	Cool
06/11/2008	3	BLIND TEST GRID	720	832	72	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/11/2008	3	BLIND TEST GRID	832	846	14	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Replacing batteries.	NA	NA	Sunny	Cool
06/11/2008	3	BLIND TEST GRID	846	1040	114	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/11/2008	3	BLIND TEST GRID	1040	1120	40	BREAK/LUNCH	Lunch	NA	NA	Sunny	Warm
06/11/2008	3	BLIND TEST GRID	1120	1153	33	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/11/2008	3	BLIND TEST GRID	1153	1218	25	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Switching to yard tractor.	NA	NA	Sunny	Warm
06/1120/08	3	CALIBRATION LANES	1218	1352	94	COLLECTING DATA	Collecting data, performed static testing.	GPS	Linear	Sunny	Warm
06/11/2008	3	CALIBRATION LANES	1352	1400	8	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration, min	Operational Status	Operational Status Comments	Track Method	Pattern	Field Conditions	
06/12/2008	2	CALIBRATION LANES	448	525	37	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
06/12/2008	2	BLIND TEST GRID	525	728	123	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/12/2008	2	BLIND TEST GRID	728	820	52	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Verifying data.	NA	NA	Sunny	Cool
06/12/2008	3	BLIND TEST GRID	820	1002	102	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/12/2008	3	BLIND TEST GRID	1002	1045	43	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Verifying data.	NA	NA	Sunny	Warm
06/12/2008	3	BLIND TEST GRID	1045	1118	33	COLLECTING DATA	Collecting data, performed static testing.	GPS	Linear	Sunny	Warm
06/12/2008	3	BLIND TEST GRID	1118	1130	12	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Verifying data.	NA	NA	Sunny	Warm
06/12/2008	3	CALIBRATION LANES	1130	1245	75	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/12/2008	3	CALIBRATION LANES	1245	1317	32	BREAK/LUNCH	Lunch	NA	NA	Sunny	Warm
06/12/2008	3	BLIND TEST GRID	1317	1349	32	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Warm
06/12/2008	3	BLIND TEST GRID	1349	1402	13	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
06/13/2008	3	BLIND TEST GRID	453	515	22	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
06/13/2008	3	BLIND TEST GRID	515	900	225	COLLECTING DATA	Collecting data, north to south, west to east.	GPS	Linear	Sunny	Cool
06/13/2008	3	CALIBRATION LANES	900	905	5	DOWNTIME DUE TO EQUIPMENT MAINT/CHECK	Verifying data.	NA	NA	Sunny	Cool
06/13/2008	3	CALIBRATION LANES	905	922	17	DOWNTIME DUE TO EQUIPMENT FAILURE	Computer system dropped, fallen from 1-ft platform, main connector repaired.	NA	NA	Sunny	Cool
06/13/2008	3	CALIBRATION LANES	922	1015	53	COLLECTING DATA	Collecting data, performed static testing.	GPS	Linear	Sunny	Warm
06/13/2008	3	CALIBRATION LANES	1015	1205	110	DEMOBILIZATION	Breakdown end of test	NA	NA	Sunny	Warm

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

APPENDIX E. REFERENCES

1. Standardized UXO Technology Demonstration Site Handbook, DTC Project No. 8-CO-160-000-473, Report No. ATC-8349, March 2002.

2. Aberdeen Proving Ground Soil Survey Report, October 1998.

3. Data Summary, UXO Standardized Test Site: APG Soils Description, May 2002.

4. Yuma Proving Ground Soil Survey Report, May 2003.

5. Practical Nonparametric Statistics, W.J. Conover, John Wiley & Sons, 1980, pages 144 through 151.

APPENDIX F. ABBREVIATIONS

ADST	=	Aberdeen Data Services Team
APG	=	Aberdeen Proving Ground
ATC	=	U.S. Army Aberdeen Test Center
ATSS	=	Aberdeen Test Support Services
BAH	=	Booz Allen Hamilton
C	=	clutter
DPRT	=	Duke Pattern Recognition Toolbox
E	=	efficiency
EM	=	electromagnetic
EMI	=	electromagnetic induction
ERDC	=	U.S. Army Corps of Engineers Engineering Research and Development Center
ESTCP	=	Environmental Security Technology Certification Program
EQT	=	Army Environmental Quality Technology Program
EXP	=	Geosoft mathematical expression
GPS	=	Global Positioning System
GS	=	Geosoft Executable
GX	=	Geosoft Script
HEAT	=	high-explosive anti-tank
IMU	=	inertial measurement unit
JPG	=	Jefferson Proving Ground
M	=	standard deviation
MAG	=	magnetometer
METDC	=	Military Environmental Technology Demonstration Center
MM	=	MetalMapper
MMI	=	MetalMapper Inversion
N	=	repeat factor
NS	=	nonstandard
O	=	ordnance
POC	=	point of contact
QA	=	quality assurance
QC	=	quality control
RMS	=	root mean square
ROC	=	receiver-operating characteristic
RTK	=	real time kinematic
SERDP	=	Strategic Environmental Research and Development Program
T	=	period
USAEC	=	U.S. Army Environmental Command
UTM	=	Universal Transverse Mercator
UXO	=	unexploded ordnance
YPG	=	U.S. Army Yuma Proving Ground

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